Estimating O&S Costs
A System Dynamics Approach

Capt Chris Purvis

Air Force Institute of Technology - - Graduate Student

MISTAKES

It Could Be that the Purpose of Your Life Is Only to Serve as a Warning to Others.

Disclaimer

Two commercially developed System Dynamics software packages will be discussed in this briefing.

There is no Air Force endorsement (explicit or implied) of either of these packages.

Overview

- The purpose
- Importance of O&S estimating
- SD model example
- Compare to regression model
- SD approach and definition
- Advantages/Disadvantages
- Case Study
- Conclusion

Purpose

To explain the usefulness of System Dynamics modeling

What is wrong with current modeling tools?

- Current estimating techniques lack feedback influences
- Often simplistic in approach (not in development)
- Development of CERs can take the "thinking" out of the equation
- Limited by available data - changing accounting systems

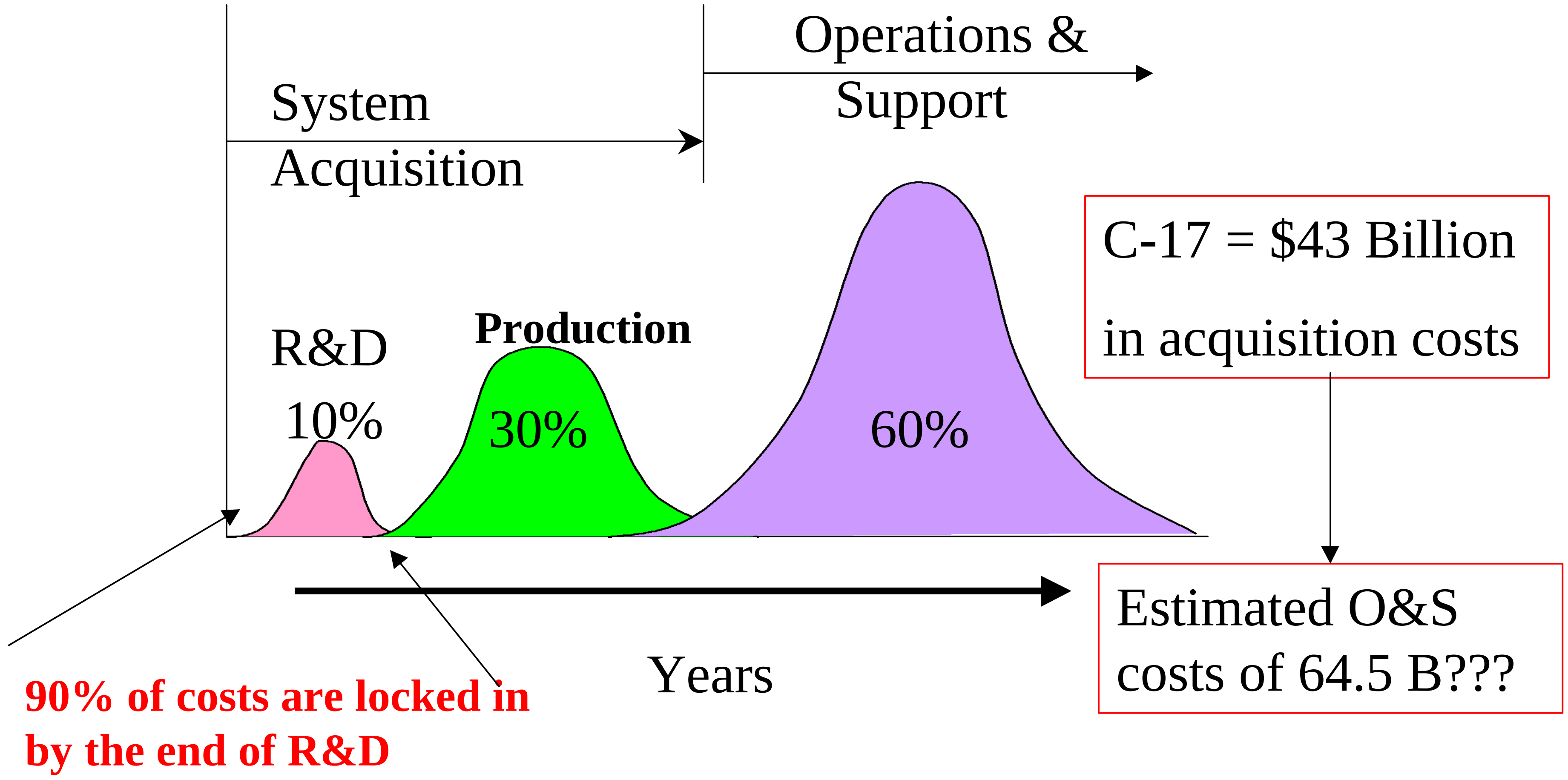
System Dynamics uses a different methodology - additional insight can be garnered through the use of this tool

I am presenting a Cost Estimating Methodology/Tool

Not a Cost Estimate

Why Estimate O&S Costs?

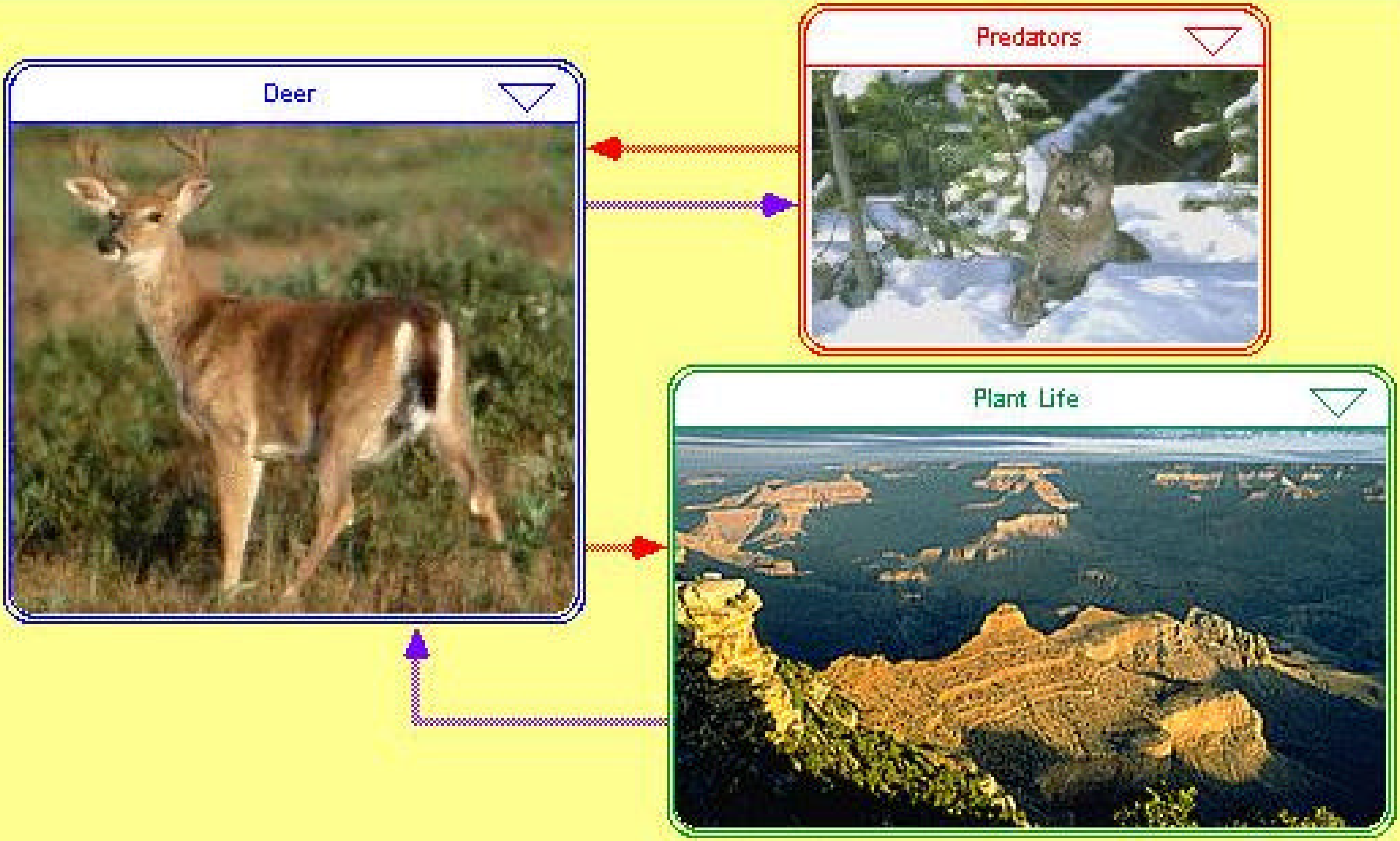
- Operations & Support Costs - 60% of system cost



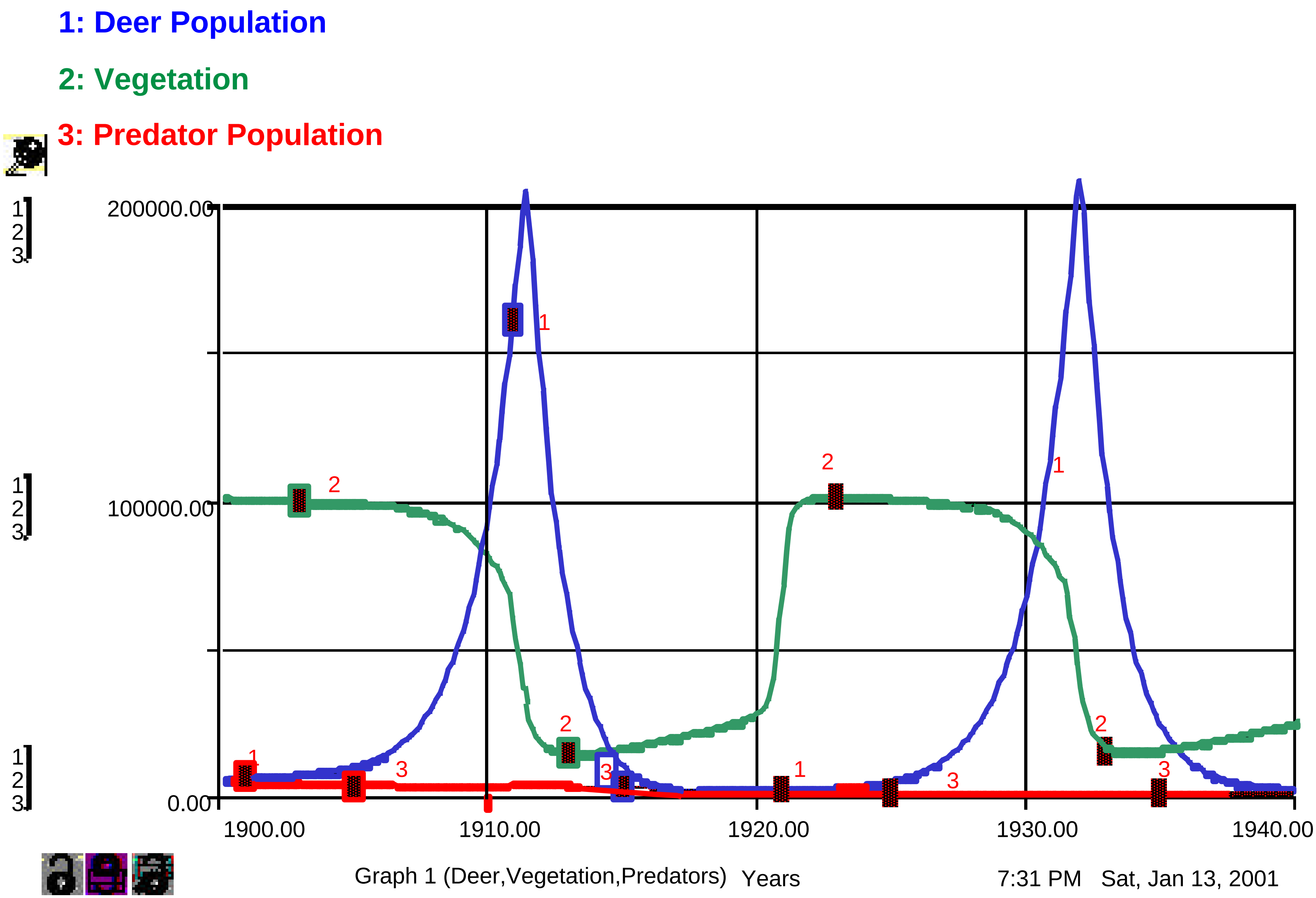
System Dynamics Example

- Show how System Dynamics “works”
- Provide a basis of reference
  - -- for use on O&S costs
  - -- for use in decision making

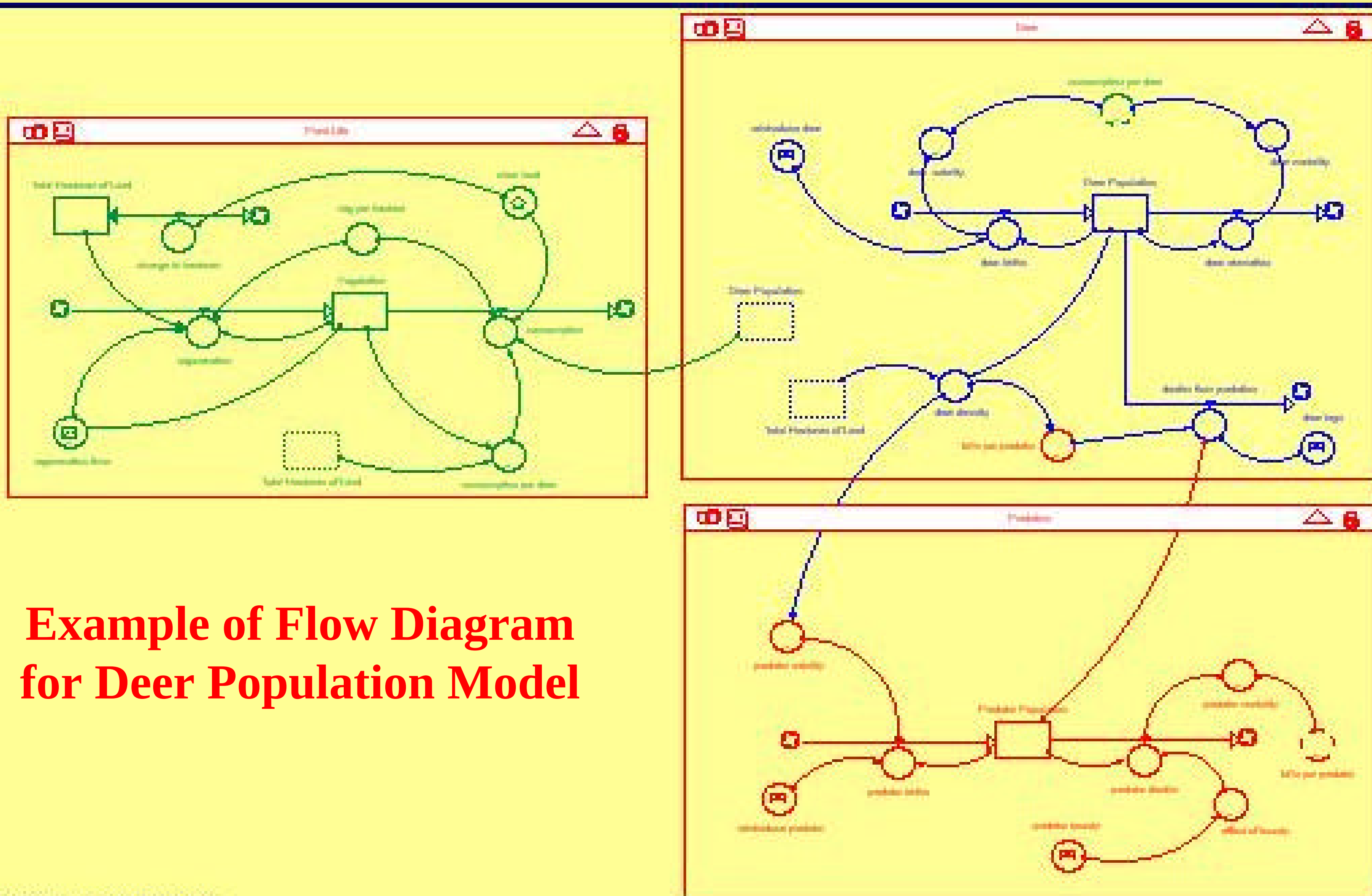
Dynamics of Deer Population



Past Population Behaviors



Formulate-Test-Verify



Example of Flow Diagram for Deer Population Model

Fill in Data/Check Equations

Deer

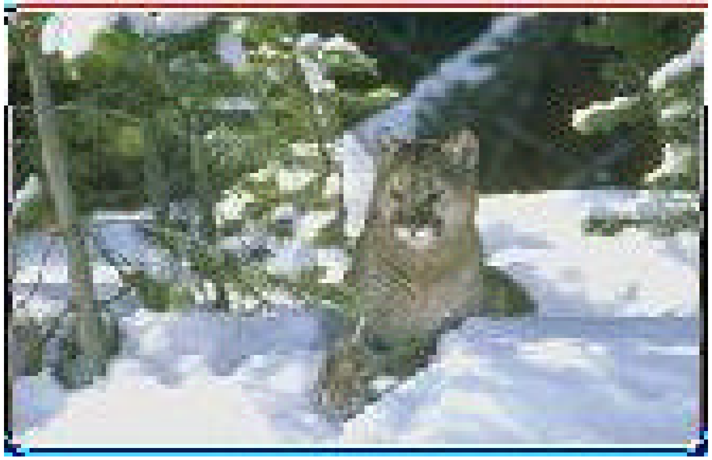
Deer_Population(t) = Deer_Population(t - dt) + (deer_births - deer_starvation - deaths_from_predation) * dt
INIT Deer_Population = 5000
INFLOWS:
deer_births = (Deer_Population*deer__natality)+reintroduce_deer
OUTFLOWS:
deer_starvation = Deer_Population*deer_mortality
deaths_from_predation = (Predator_Population*kills_per_predator)+deer_tags
deer_density = Deer_Population/Total_Hectares_of_Land
deer_tags = 0
reintroduce_deer = 0
deer_mortality = GRAPH(consumption_per_deer)
(0.00, 0.81), (0.1, 0.79), (0.2, 0.74), (0.3, 0.68), (0.4, 0.55), (0.5, 0.47), (0.6, 0.44), (0.7, 0.4), (0.8, 0.4), (0.9, 0.4), (1, 0.4)
deer__natality = GRAPH(consumption_per_deer)
(0.00, 0.015), (0.1, 0.065), (0.2, 0.145), (0.3, 0.345), (0.4, 0.675), (0.5, 0.86), (0.6, 0.97), (0.7, 0.985), (0.8, 0.995), (0.9, 0.995), (1, 1.00)
kills_per_predator = GRAPH(deer_density)
(0.00, 0.00), (1.00, 0.04), (2.00, 0.1), (3.00, 0.275), (4.00, 0.625), (5.00, 1.00), (6.00, 1.50), (7.00, 2.08), (8.00, 2.60), (9.00, 3.00), (10.0, 3.00)

System Dynamics Modeling
- a simple example – Deer Population
Conceptualization

- Define the question – What policies will foster a static population
  - minimize population collapse

- Do we have actual data?
- What are the known or expected behaviors?
  - Deer
  - Predators
  - Vegetation

Validate - Implement



- Run Simulations
  - Vary policies
    - Re-introduce deer
    - Deer tags/hunting permits
    - Re-introduce predators/hunting permits
    - Planting/clear cutting – vegetation

- Implement Policy that meets program objectives.
- Continue to monitor to increase Confidence

SD vs. Regression - predicting failures

Which is easier to understand?

Question, how many failures will occur ?

$$\hat{Y} = 3.4 + .109(hours) - .0004(hours)^2 + .073(Lands) + .105(Stops) + .125(Age) - .00136(Age)^2$$
$$- .0013(Hours*stops) - .00000001(Hours*stops)^2 + .0005(Lands*hours) - .001(Stops*lands)$$
$$- 1.98(\text{Winter})$$

What is the impact on cost?

$$\hat{Y} \text{ x Cost\_Factor} = \text{Total Cost}$$

18,000 data points

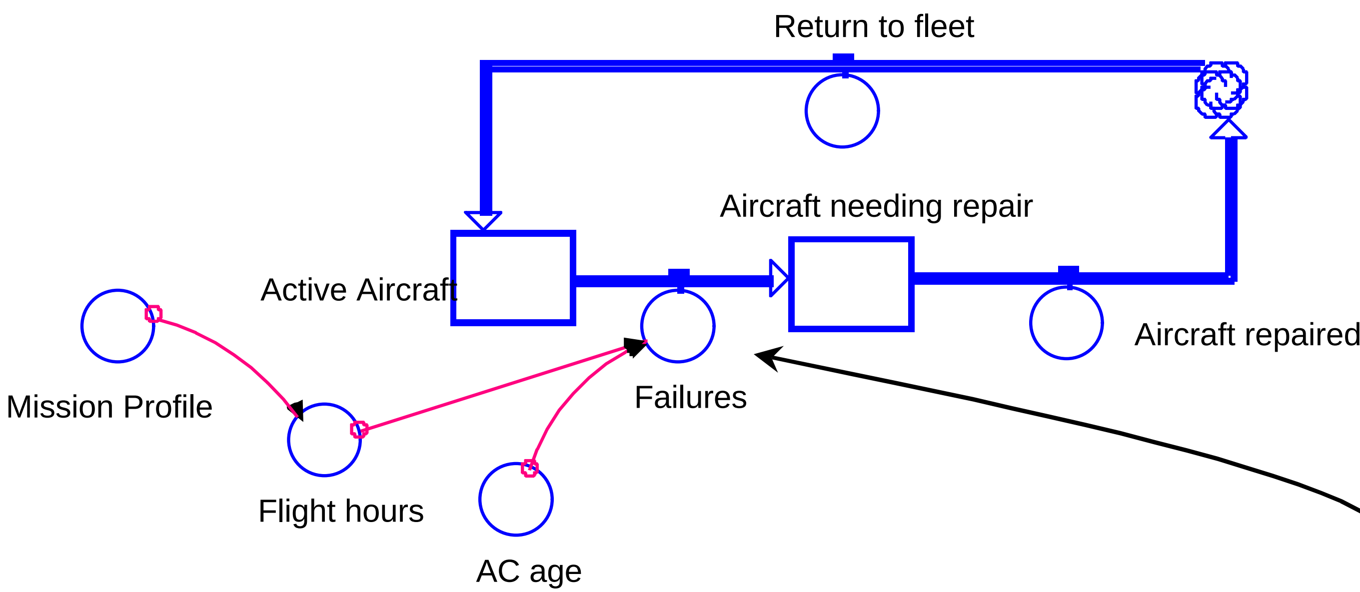
Full model regression

Reduced to significant interactions

$R^2 = .3$

SD vs. Regression - predicting failures

Which is easier to understand?



Question, how many failures will occur?

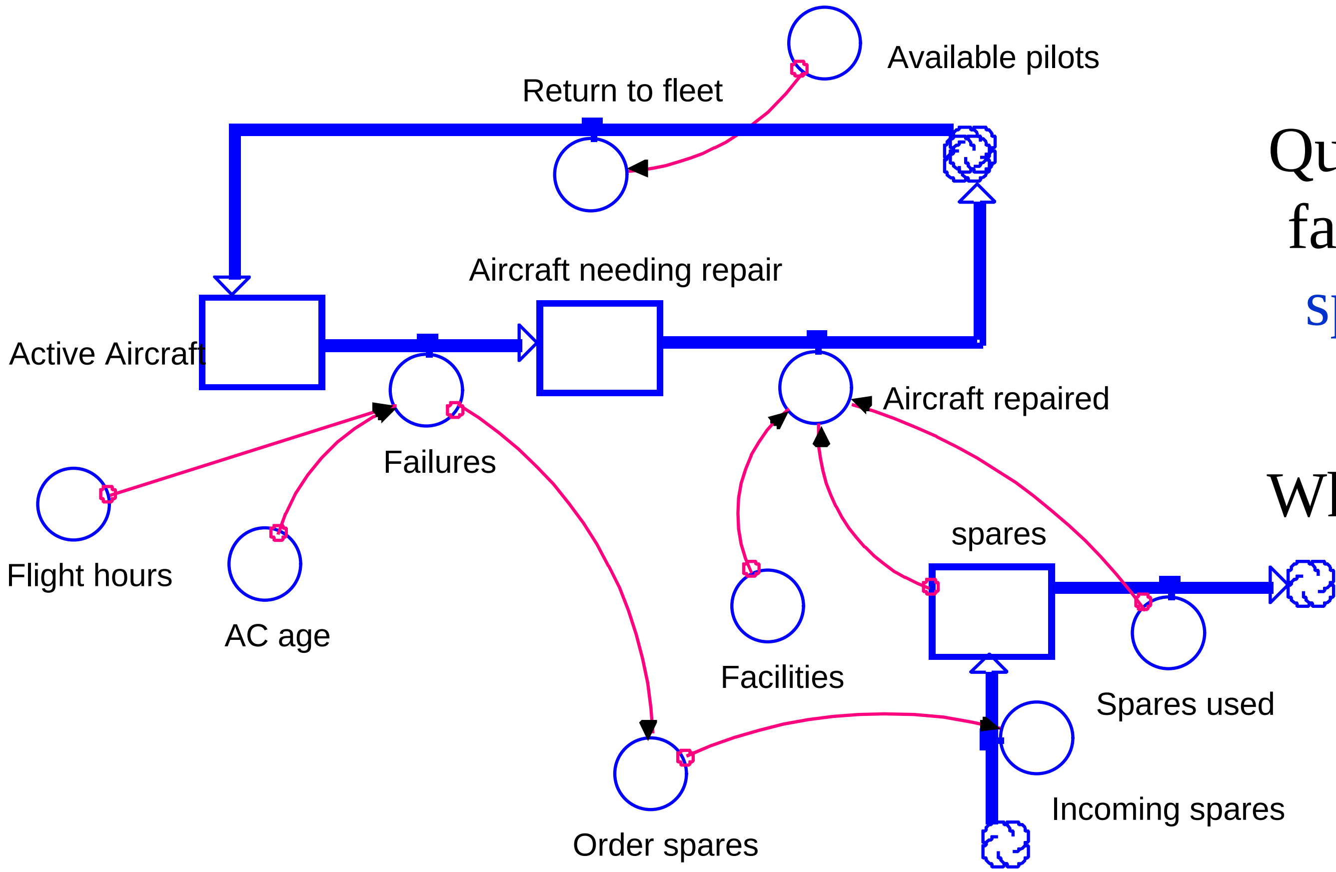
What is the impact on cost?

= Failures X Cost_factor

Same model, but SD easier to “see” influences

SD vs. Regression - predicting failures

Which is easier to understand?



Flexibility

Question? How many failures will occur if spares delayed one month?

What is the impact on cost?

Solution: Add some structure

$$\hat{Y} = 3.4 + .109(hours) - .0004(hours)^2 + .073(Lands) + .105(Stops) + .125(Age) - .00136(Age)^2$$
$$- .0013(Hours*stops) - .00000001(Hours*stops)^2 + .0005(Lands*hours) - .001(Stops*lands)$$
$$- 1.98(\text{Winter})$$

Can't do, data not collected

System Dynamics?

System Dynamics Modeling Approach

SD Approach	What it means
Conceptualization	Define expected behaviors/co-dependencies
Formulation	Build Model - Flow diagram - Iterative process
Testing -	Does the model work?
Verification -	Does the model work as expected?
	- Dr. Forrester's 18 step method
Validation	Slowly build confidence that the model is correct
	No "one time test" of validity!
Implementation	Ultimate proof of validity - Does customer use it?

“Textbook” definition of System Dynamics

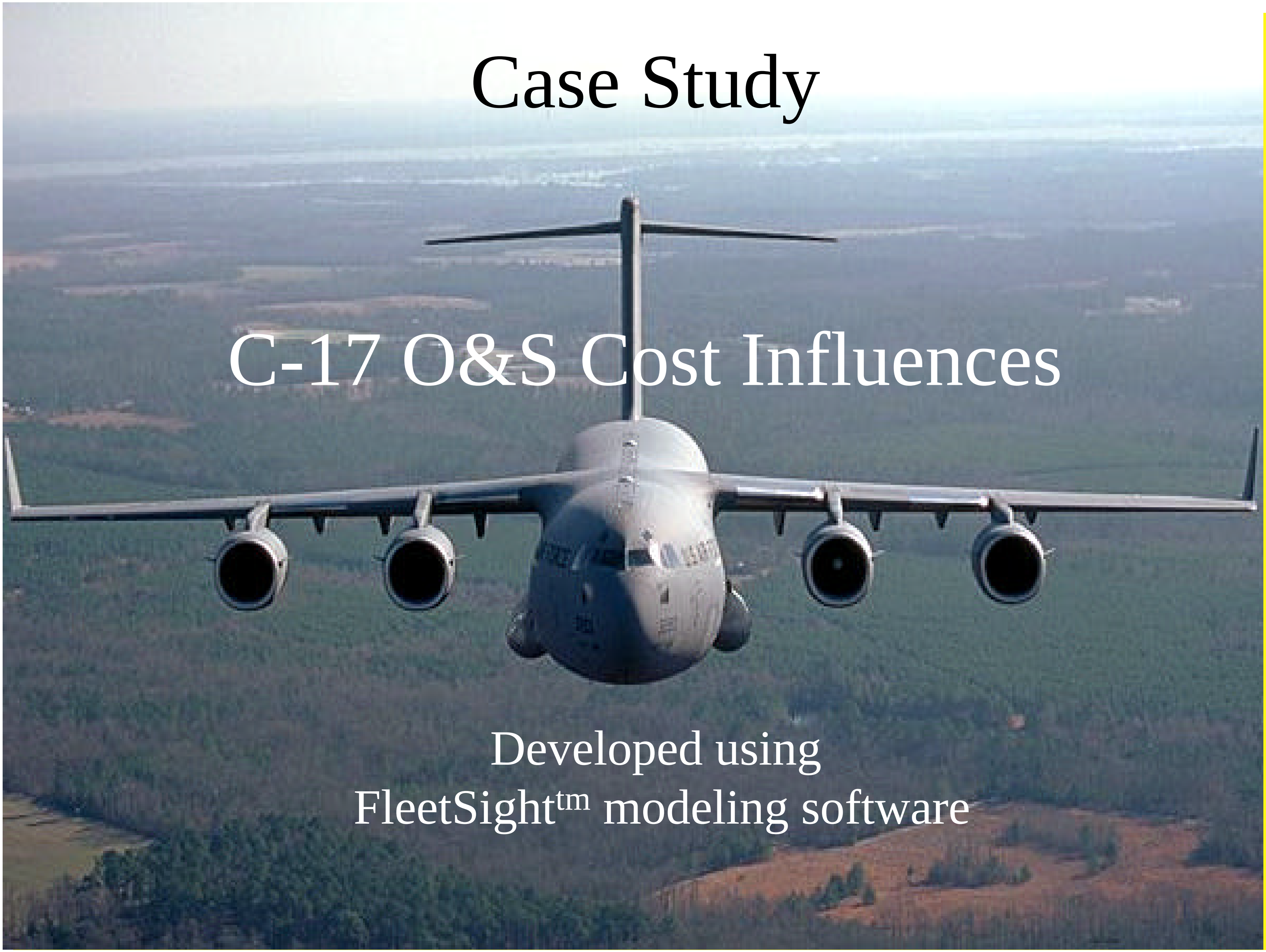
An evolving, non-linear, causal based simulation technique, used by decision makers to explore dynamic behaviors

SD Advantages

- Data requirements – less intensive
  - Diminishing sources of cost information?
  - Inconsistencies in cost data reporting over last 20 years
  - Relationships based on experience – not proofs of causation
- Intuitive – easy to understand
  - Reference mode
  - Flow diagram
- Models “Dynamic” or feedback relationships
  - Circular Logic
    - Exponential growth/Decay
    - Oscillation
    - Co-flow
- Combination Analogy/Parametric/Simulation modeling

SD Disadvantages

- Excessively Complex Models
  - Desire to avoid omission of important elements
  - Easy to add structure, difficult to reduce structure
- Possible to exclude important detail
  - Focus too narrow – attempt to eliminate all uncertainty
- Escalation of Commitment
  - Propensity to only go forward –add more complexity to solve modeling issues.
- Tendency to become stalemated in unending formulation


Case Study
C-17 O&S Cost Influences
Developed using
FleetSight™ modeling software

Why SD appeals to C-17 Costers

- Predicting failures as system ages
- Transitioning to “Commercial” systems
  - Limited cost data
  - Need a tool for negotiating “price”
- Acknowledge the need for a long-run planning tool for efficient resource allocation
  - Budget reductions
    - What-if drills
    - Consequences
  - Defensive cost model

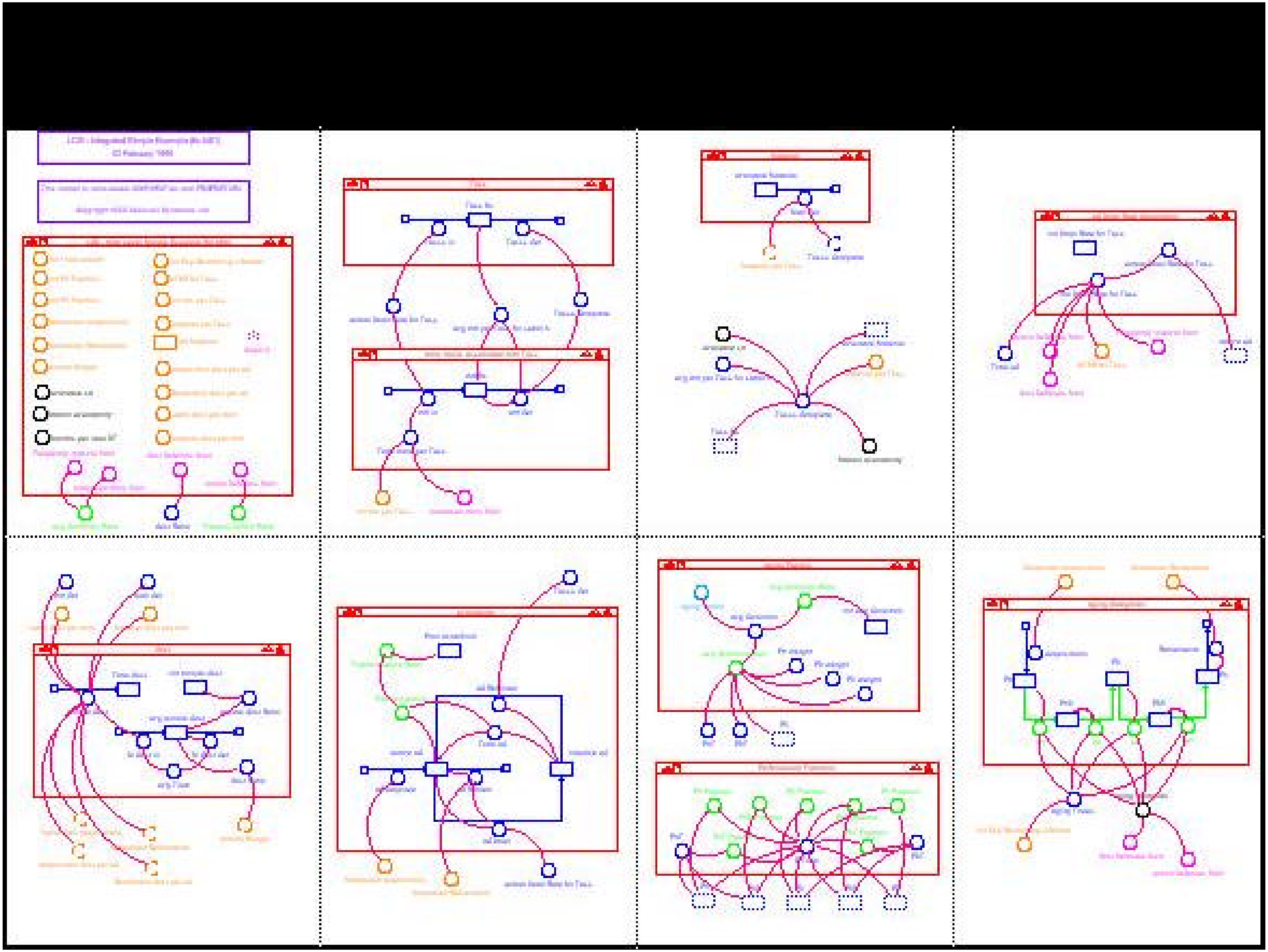
Commissioned an AFIT Graduate Student to learn and independently test the software, using C-17 program data and expert opinion of expected behaviors, before committing resources to the endeavor.

*FleetSight*ä Advanced Life Cycle Support Simulation Software

Advantages	Disadvantages
Proven Logic flows	Can’t add structure/logic
Static Structure	No Gov’t wide usage
Logical Inputs	Combination of actual and dynamic behaviors - can stifle dynamic behavior influences
Ease of modeling	
Consistent modeling - products - services	
Activity Based Costing	

Current C-17 Cost Estimating Tool
Boeing Joint Cost Model

- Pricing model
- Generate negotiated costs for C-17 Flexible Sustainment Contract
- Relevant Range = 7 years
- Labor costs fixed
- Materials costs variable to flight hours
  - Roughly straight line relationships



Expert's Assumptions

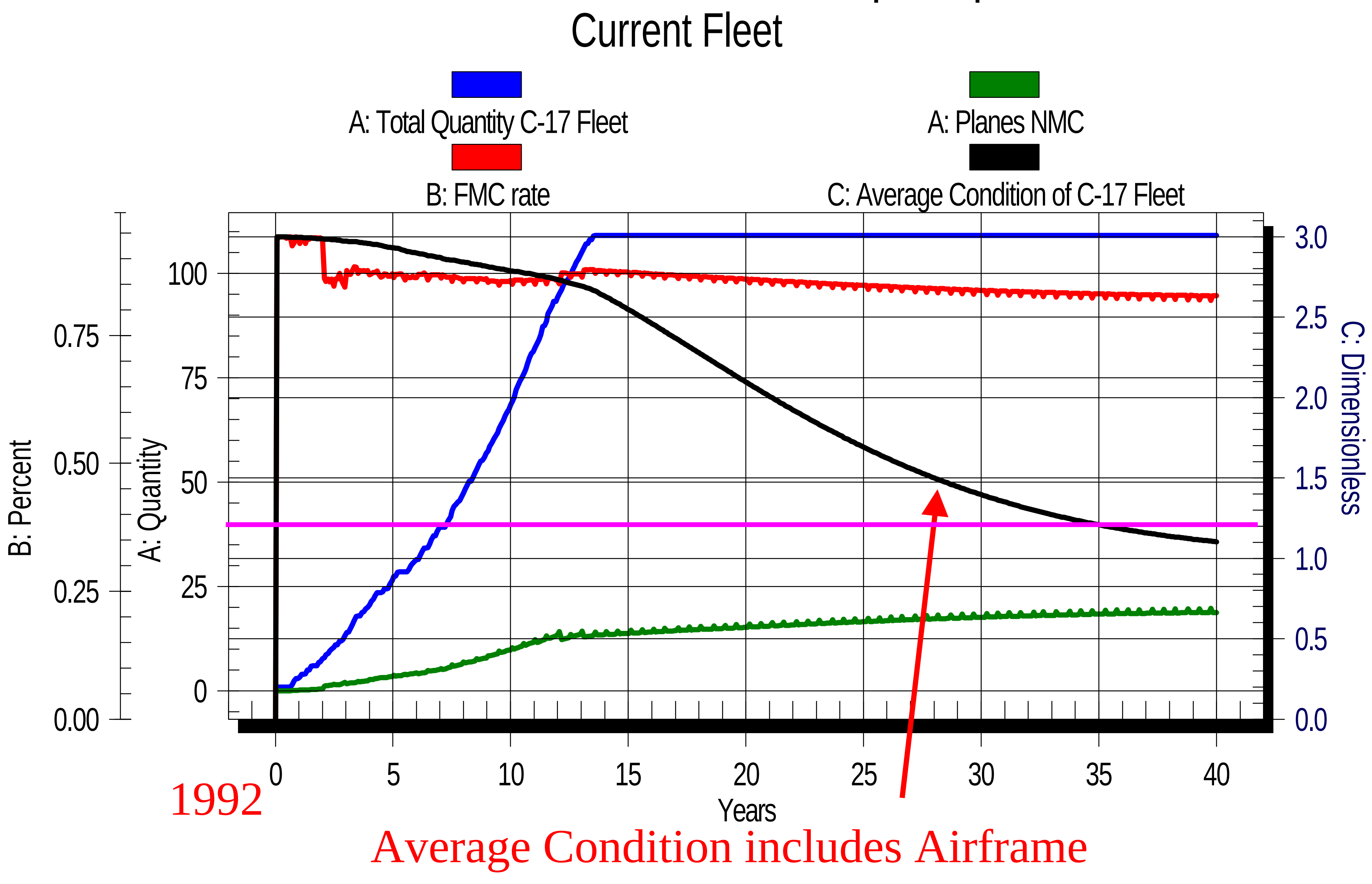
Illuminate the Possibilities

- Compare F/S model to current cost model
  - influence of NOT painting
  - Influence of flight hours - double F/H requirements

- Evaluate for reasonableness
- Simulate different “strengths of influence”
  - none
  - little
  - moderate
  - significant

Prepare to Simulate

- First - What is current status?   Develop "expected" baseline



Step one - Hypothesize Behavior

- What will be the effect of NOT re-painting the fleet?
  - Increased aging on the airframe?
    - effects of corrosion - average condition drops faster?
  - Reduced aircraft availability?
    - increased maintenance requirements
      - drop in A/C availability?
    - increased maintenance time
      - corroded bolts/panels/fasteners - increase in costs?

Ideally, perform experiments to determine values - however, due to lack of data, we must hypothesize effect - simulate

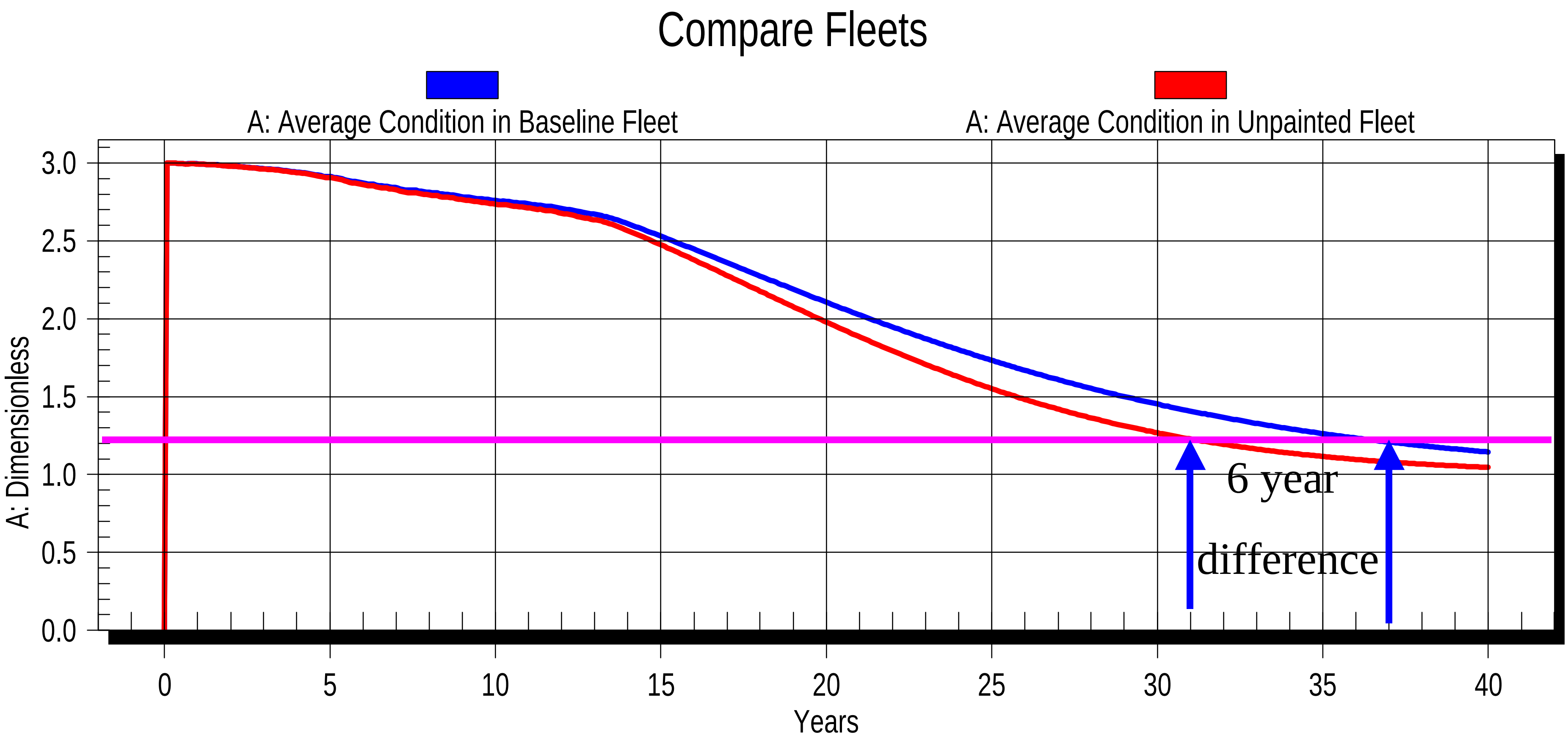
Step Two - Enter data/make assumptions

- Current paint has 12 year expected lifespan
- Paint age effects airframe “age”
- Airframe age effects aircraft “age”
- Failure rates increase as service life ends

According to the Advisory Group for Aerospace research & Development, corrosion damage can be seen as early as three days after a scratch to bare metal.

(Protective coatings have a high impact on Corrosion Resistance)

Step Three - Simulate



Hypothesized result - effect of not re-painting the fleet is a 6 year decrement in the useful life of the C-17 fleet (6*120= 720 cargo years)

Differences can be seen as early as 6 years into the fleet's service

Compare against other models

- C-17 Joint Cost Model - effect of not painting?
  - First 7 years = $3 million savings
  - Total over 40 years? = $23.4 Million savings
    - 40 years/5 year interval = 8 per AC *120 AC = 960 * $24,000

- FleetSight generated results?
  - 720 cargo years lost = 24 C-17 equivalents
    - 720 years ÷ 30 years/AC = 24 C-17s
  - **Actual cost to Air Force (at Must Cost $ = $3.6B) irregardless of cost impacts on other components!**

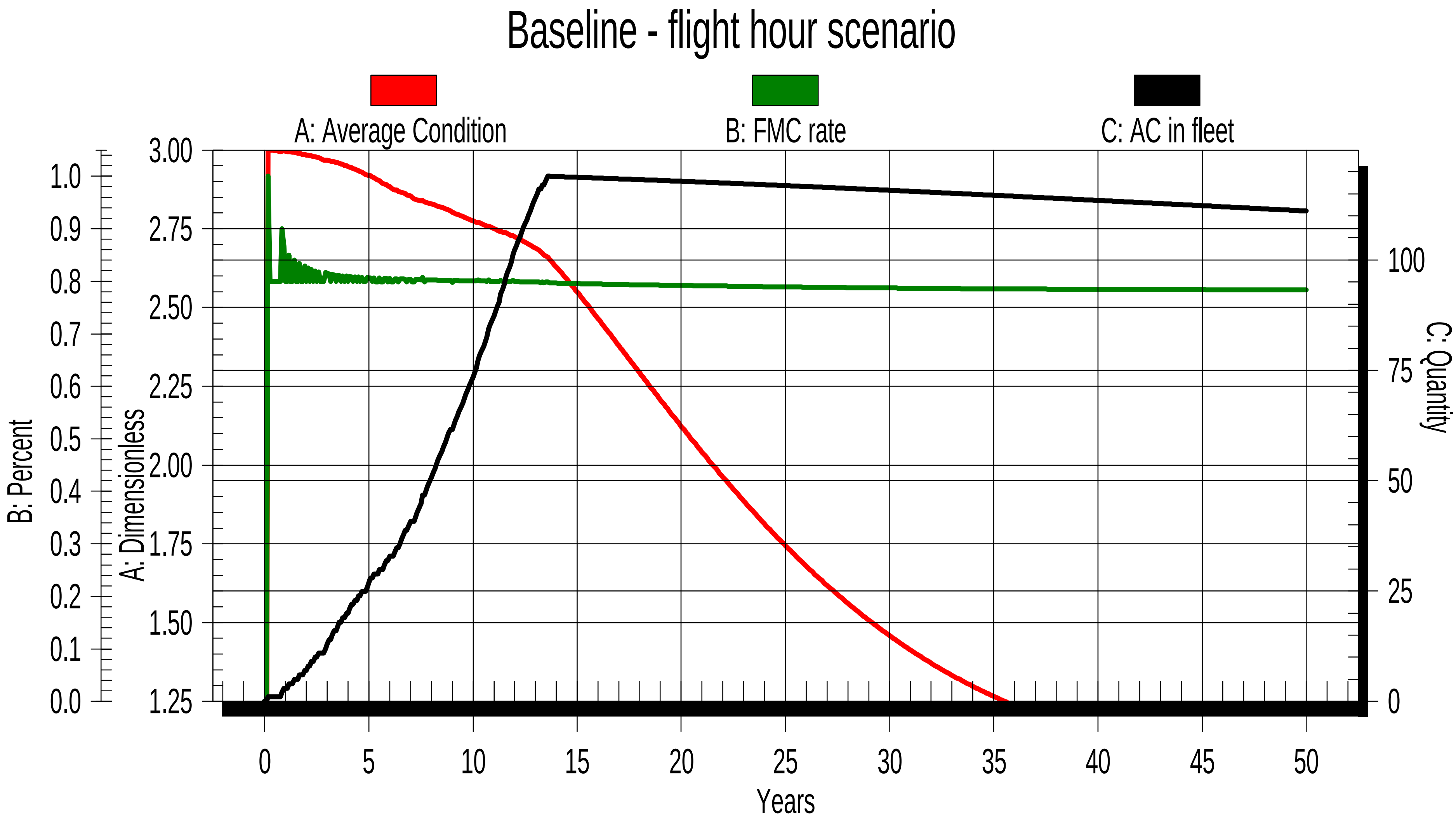
A Comprehensive Look

Cost of increasing Ops Tempo (Double Flight Hour Usage)

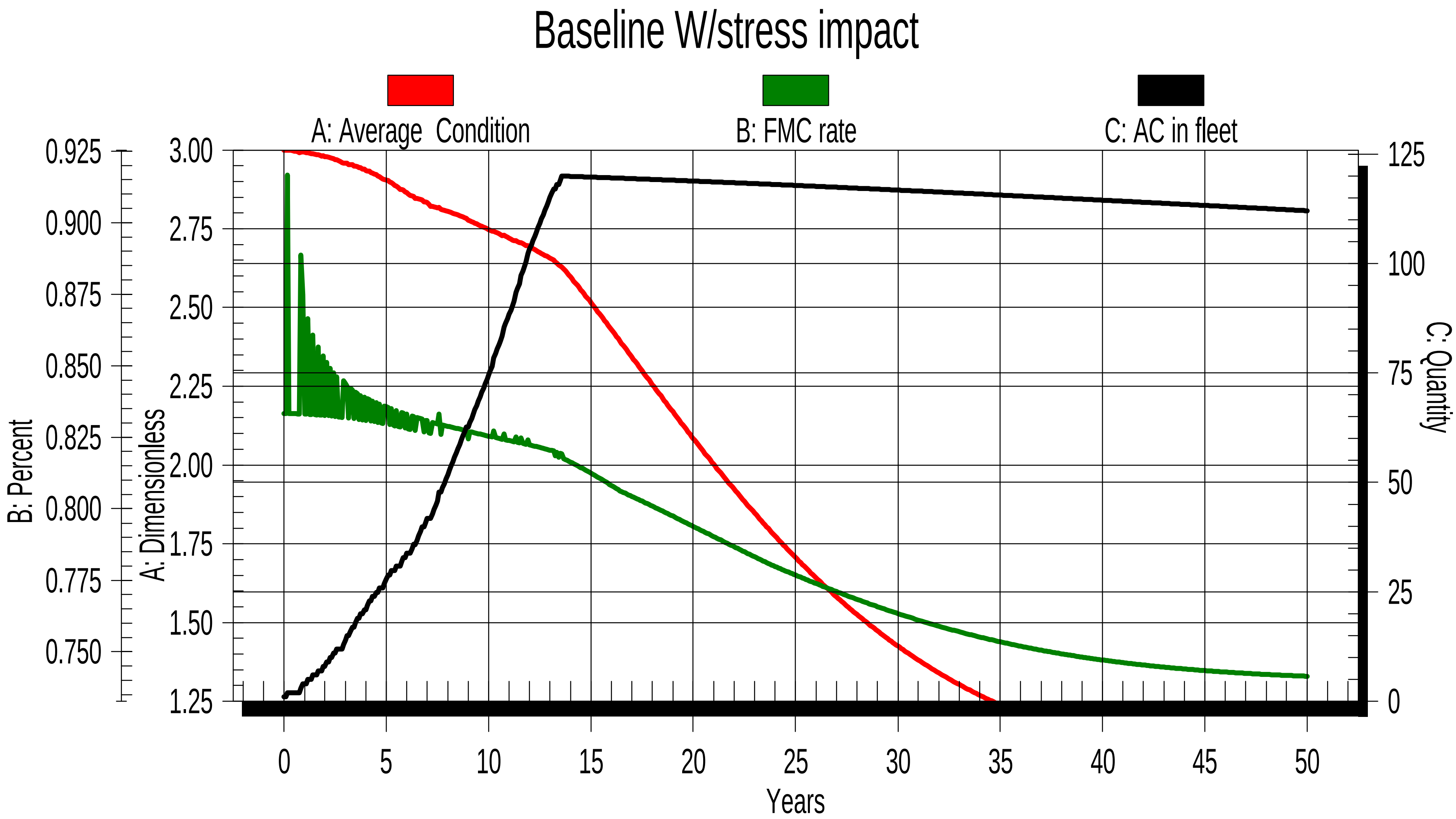
- Plan against same baseline
- Hypothesize results
  - Increased tempo results in stressed fleet
    - Constant failure rates per Flt/Hr result in more failures per day - increase spares requirements
    - If high dependency, stressed fleet ages faster (cracks, accidents, maintenance problems)
      - costs increase at an increasing rate
      - manpower usage increases
- Compare against current model

Current Status

No Stress influences

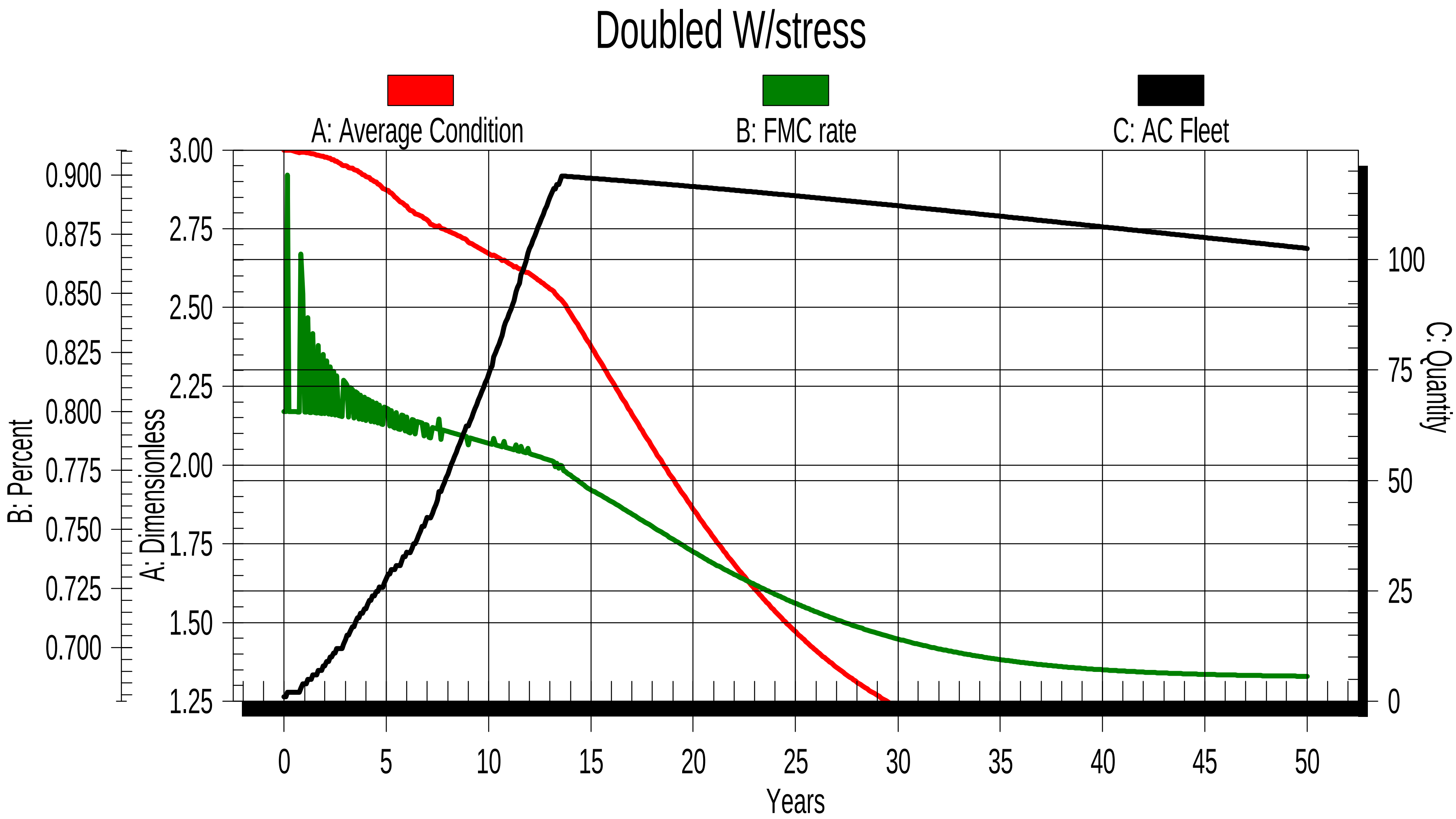


Possible Impact - Stress Influence

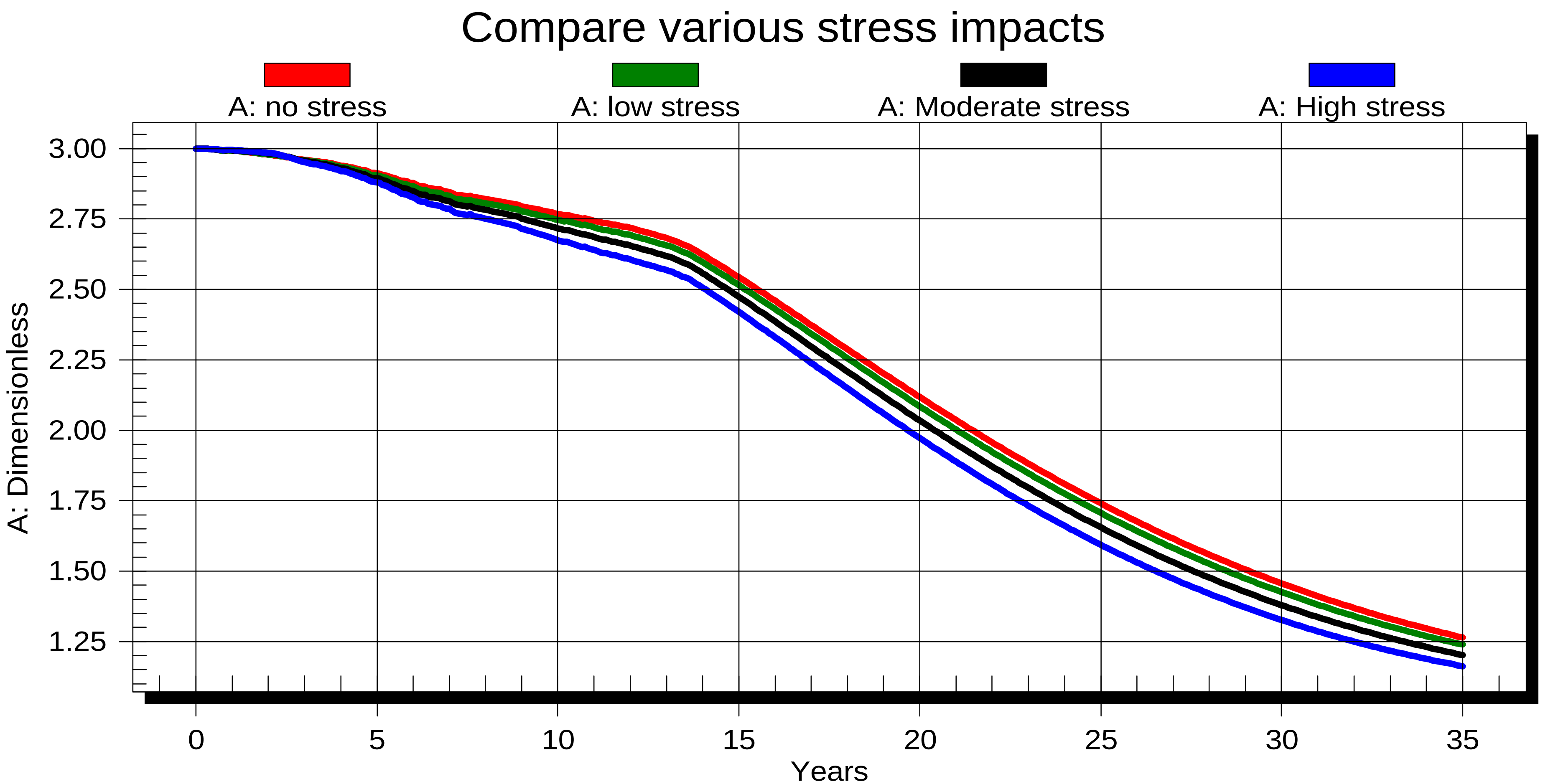


Possible Impact Doubled Flight Hours

same stress multiplier



Compare Stress levels - Baseline



Hypothesized result - effects of stress alone are a minor indicator on a "low stressed," however it acts as an aging multiplier as the fleet becomes more stressed - times of war, humanitarian missions, etc.

What about costs?

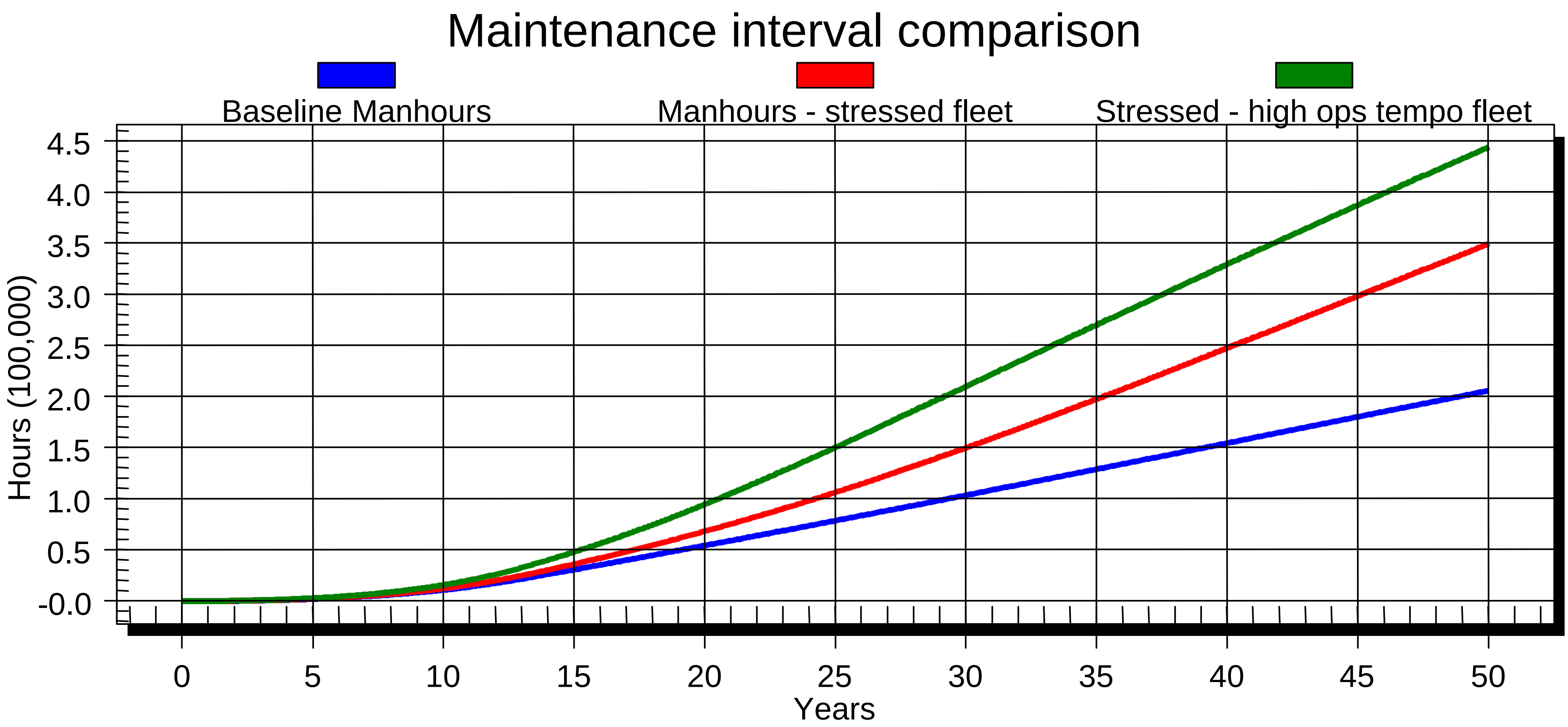
- Assume “high” stress influence
  - Stressed fleet ages faster
- Hypothesize behavior
  - Fleet reaches “end of useful life” even quicker
  - Dramatic decrease in FMC rate
  - Dramatic increase in Maintenance costs

C-17 Stats

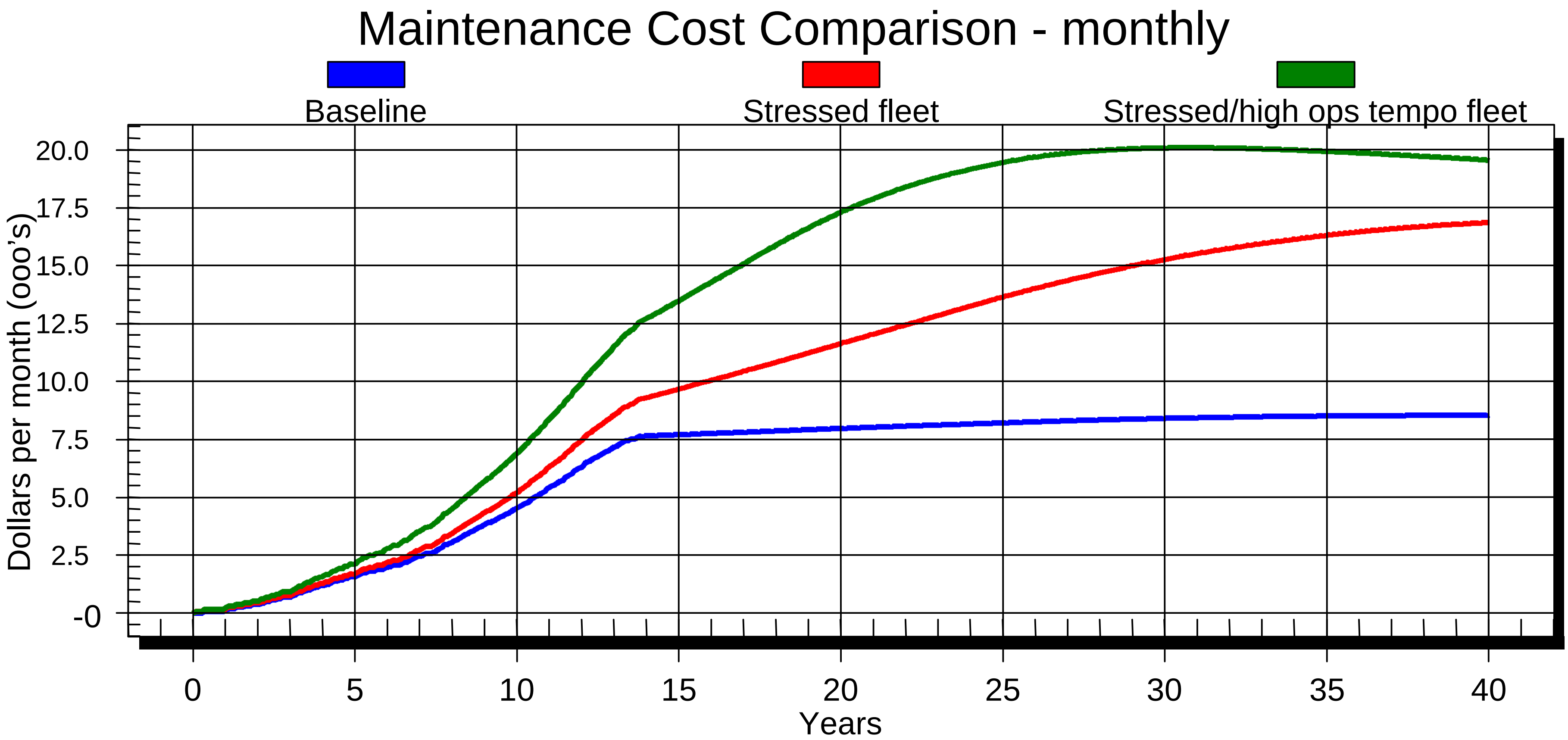
- At current profile
  - Maintenance man-hours/flying hour = 18.6
    - $ per hour average - assume $20 (hourly SSgt pay)
  - 120 total aircraft buy (for USAF purposes)
  - Life expectance 30,000 flight hours, 30 years (each aircraft)
  - C-17 Failure rate? - used estimated attrition rate (.1 per 100,000 flt hrs)

Assume no spares/resource constraints

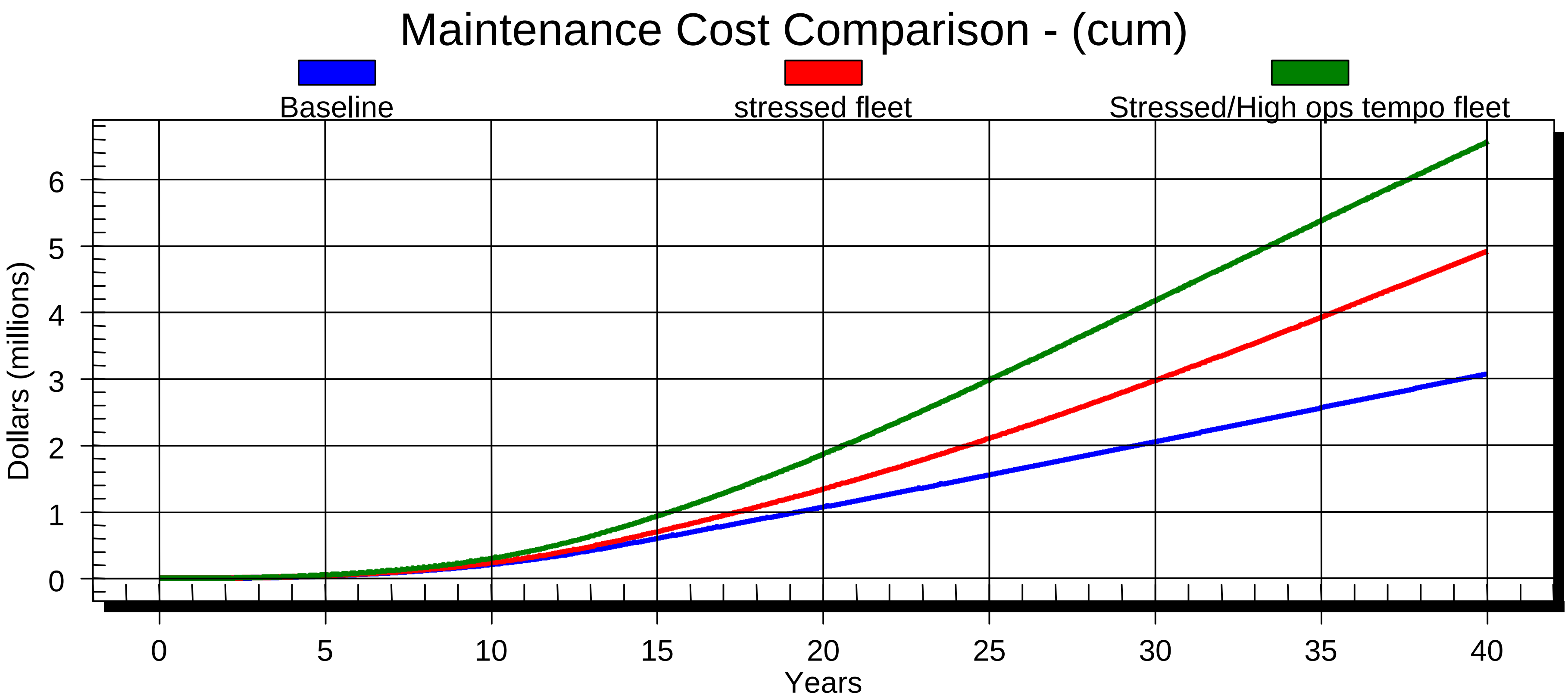
Strong Influence



Strong Influence



Compare



Hypothesized result - effect doubling Ops Tempo is a 5 year decrement in the useful life of the C-17 fleet, and a greater than doubling in Costs, and Spares requirements

Comparison between models

- Current model
  - Double flight hours impacts materials only
    - Direct relationship
- SD model
  - Doubled flight hours impacts
    - Available Aircraft
    - Service life of Aircraft
    - Increased maintenance costs
    - Increased spare requirements

A new “Swiss Army” tool?

NO!!!

- SD models should never replace current short term pricing models.
  - Real value is for long-range planning and behavior analysis
  - Works best for decision making
    - Do not want to foster a short term thinking mentality
    - Ideally used before a system is developed
      - Address - spares - reliability - COST - and schedule trade-offs

Conclusions

- System Dynamics addresses some of the shortfalls of other cost estimating models

- *FleetSight ä* is one possible resource to meet these needs
- More analysis, detailed modeling needs to be done

C-17 – System Dynamics Evaluation

Questions?